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EFFECTS OF PRESSURE SWEEP ON ACOUSTIC IMMITTANCE MEASURES IN EARS WITH NORMAL AND INCREASED ADMITTANCE

ABSTRACT

Purpose: To investigate the effects of pressure sweep direction (conventional and reverse) and pressure sweep rate (200 daPa/sec and 50 daPa/sec) on tympanometric peak pressure (TPP) and admittance value, and to evaluate the effect of the obtained TPP on the ipsilateral acoustic reflex thresholds (ARTs) in individuals with high and normal compliance middle ear systems.

Methods: Two groups,25 ears with healthy middle ear admittance (group I) and 19 ears with increased admittance (group II) were evaluated on tympanometric measures for within group comparisons. Tympanometry were performed in four conditions at two pressure directions (conventional and reverse) and two pressure rates (high and low). In addition, ipsilateral ARTs at octave frequencies between 500–4000 Hz for the TPP obtained for each of the four conditions.

Results: Our results indicated significant differences in the measured TPPs across the conditions for both groups, but we did not find any significant differences in the admittance measures across the conditions for both groups. Our further analysis of the ipsilateral ARTs for TPPs revealed significant differences for between-conditions for individuals with high compliance middle ear systems at frequencies over 1000 Hz. The findings of the present study suggest that low (better) ARTs are elicited with lower variability at a TPP measurement obtained with a conventional pressure sweep direction at a pressure sweep rate of 50 daPa/sec.

Conclusions: Thus, clinically it is recommended to obtain tympanometric measurements with lower pressure sweep rate at a conventional pressure sweep direction for those individuals with increased admittance.

Keywords: Middle ear,Tympanometric peak pressure, Admittance/Compliance, and Acoustic reflex

Introduction

Middle ear is the essential part of the auditory system for compensating for the impedance mismatch between the acoustic energy in the environmentandcochlear fluids in the inner ear(Moore, 2012). The optimal function of the middle ear is crucial for normal hearing phenomenasince it creates a pathway for sound to travel to inner ear. Disordered function of middle ear can affect hearing sensitivities causing conductive hearing loss.Assessing such types of hearing loss and functioning of middle ear isevaluated using impedance measurements,whichcommonly involve tympanometry with a 226-Hz probe tone and acoustic reflex threshold (ART) measurements. During the tympanometry procedure, the pressure in the external ear canal is varied systematically, and the compliance/admittance of the tympanic membrane is estimated by computing the acoustic energy reflectedback, which is utilized to identifythe functioning of the middle ear. The air pressure that coincides with the peak admittance (i.e.,at high compliance or low impedance) is calledthe tympanometric peak pressure (TPP). Clinically, tympanograms are obtained with a 226-Hz probe tone, with theair pressure swept from +200 daPa to -400 daPa at a pressure sweep rate of 200 daPa/sec. The normal middle ear function has TPP around0daPa with sharp decline as air pressure withdraws away from 0 daPa. The disordersof middle ear affect the tympanometric shape to certain tympanogram patterns (American Speech-Language-Hearing Association, 1988; Stach, 1998).In addition,the TPP has important diagnostic value in other measures of immittance audiometry. For example, the TPP is involved in measuringARTto better monitor the subtle changes in admittance due to the stapedius muscle reflex(Stach, 1998).

Factors such as the frequency of the probe signal, changes in the direction of the pressure sweep, and/or the rate of the pressure sweep in tympanometry have been reported to significantly impact the tympanometric resultsand,consequently,the ART measurements. Studies have indicated variations in admittance due to changes in the rate of air pressure(Gaihede, 1999; Kobayashi, Okitsu, & Takasaka, 1987; Margolis & Heller, 1987; Shanks & Wilson, 1986). For example, increasing the sweep pressure rate from 200 daPa/sec to 400 daPa/sec has resulted inhigher admittance and changed the complexity of the TPP(Margolis & Heller, 1987).Feldman, Fria, Palfrey, and Dellecker (1984) reported shifting of TPP to more negative pressure and increased admittance in individuals with normal middle ear functioning. Also, Shanks and Wilson (1986)reported an increase in the TPP, peak admittance, and conductance by increasing pressure rate from 12.5 daPa/sec to 50 daPa/sec with probe tones of 226-Hz and 678-Hz.Additionally, various studiesalso have found changes in the amplitude and shape of the tympanogram when the direction of the pressure sweep is changed. Mainly, the conventional direction (positive to negative) results in a higher admittance than the reversedirection (negative to positive), and exhibits more complex notching(Alberti & Jerger, 1974; Margolis & Smith, 1977; Van Camp, Creten, Vanpeperstraete, & Van de Heyning, 1980; Wilson, Shanks, & Kaplan, 1984).Thus, the effects of these factors must be considered when diagnosingthe conditions of the middle ear system(Creten & Van Camp, 1974; Koebsell & Margolis, 1986; Margolis & Heller, 1987; Shanks & Wilson, 1986).

However, most of thecited studies above have revealed variabilityin tympanometric measurements associated with the pressure sweep direction andthe sweep rate,mainly for individuals with normal middle ear functioning. Only limited numbers of investigations werereported in subjects with middle ear diseases. For example, Feldman et al. (1984) reported a change in the classification of tympanograms in about 25% of 27 children with different middle ear pathologies by changing rate of pressure. More recently,Gaihede, Bramstoft, Thomsen, and

Fogh (2005) performed bidirectional tympanometry on 57 children with serous otitis media and revealed that higher TPP pressure differences were noted in these children with middle ear pathology. In addition, only a few studies have explored the effects of these variations in tympanometric measures onART measurements.The ART is considered to be maintained close to its maximum compliance value when the external air pressure varies within a range of ±80 mm H_2O(Rizzo & Greenberg, 1979). DiGiovanni and Ries (2007) further monitored ARTsat seven different pressure values with reference to TPP and revealed that apressure of -50 daPa (relative to TPP)has better ARTsespecially forsubjects with a high peak compensated static acoustic admittance.

Overall understanding of these findings indicates a lack of information aboutthe variations in TPP due to the changes in the mode of pressure sweep and pressure rate inears withdifferent admittance categories. Thus, furtherevidence needs to be providedwith respect to the monitoring of the acoustic reflex thresholdsofTPP (measured using different tympanometry procedures) of these individuals.Research has shown that TPP can overestimate the middle ear pressure by 30–70 daPa when higher pressure sweep speeds are used,particularly for individuals with small middle ear volumes or hypermobile tympanic membranes(Renvall & Holmquist, 1976). Similar results were also noted for changes in pressure direction especially in children with secretory otitis media(Gaihede et al., 2005). Sun, Shaver, and Harader (2013) reported hypercorrection of admittance and gradient in middle ears with negative pressure. Hence, the present study measured the effects of sweep direction (Conventional, +200 to -400 daPa;Reverse, -400 to +200 daPa) and sweep rate (200 daPa/sec and 50 daPa/sec) on TPP, and determinedthe effect ofthe TPPobtained in this manner on the acoustic reflex thresholdsof individuals with normal middle ear function andincreased compliance middle ear conditions. These results are an advantage forthe accurate diagnosis of middle ear conditions, especially in individuals with high admittance.

METHODS

Participants

A total of 44 individuals (aged 15–65 years) participated in the present study. We divided the participants into two groups based on the admittance values obtained using tympanometry with 226-Hz probe tone. Group I included 25 participants (12 males and 13 females)witha normal middle ear status (17 participants with an *A* type [0.5-1.75 mmho] tympanogram and 8 participantswith an A_S type[<0.5 mmho] tympanogram). All of these participants had normal hearing sensitivity on pure-tone audiometry and acoustic reflexes at all octave frequencies between 500–4000 Hz in the tested ear.Only oneear was selected at random for performing the listed procedures and for inclusion in the data analysis.Group II included 19 participants i.e. 19 ears (10malesand 9females) with increased middle ear compliance, i.e.,an A_D type tympanogram (>1.75 mmho)and presence of normal or elevated acoustic reflexes at all octave frequencies between 500–4000 Hz.All the participants had voluntarily participated and provided their informed consent prior to enrolment in the study.The procedure used in this study adhere to the tenants of the 1964 declaration of Helsinki and in accordance with the guidelines recommend from the institutional ethical committee.

Procedure

Followingthe hearing assessments i.e. Pure tone audiometry and immittance evaluation,and otological examinationsin a sound-treated acoustic room, all the participants were asked to seat comfortably in an armchair. The participants were instructed to remainquietwithout any head movements during the measurement to avoid any variations in the tympanometric values.Probe tube was inserted in the ear canal to obtain a hermetic seal so to record the tympanogram and acoustic reflex threshold. To lessen the chances of disturbing the airtight seal of the probe tube, we provided intermittent breaks between the testing procedures, only when a participant insisted.A calibrated Grason Stadler (GSI) Tympstar version 2 Immittance meter was used to measure the TPP, admittance, and ipsilateral ART at octave frequencies between 500 Hz and 4000 Hz. The tympanometric measurements were performed in four different experimental conditions. Condition 1,i.e. Forward sweep direction at high rate (FSHR) included measuring the TPP and admittance values in the conventional pressure sweep direction (+200 daPa to -400 daPa)at a pressure sweep rate of 200 daPa/sec. Condition 2, i.e. Reverse sweep direction at high rate (RSHR) involved measuring the TPP and admittance values in the reverse pressure sweep direction (-400 daPa to +200 daPa)at a pressure sweep rate of 200 daPa/sec. Condition 3 include forward sweep direction at low rate (FSLR) measuring the TPP and admittance values in the conventional pressure sweep direction (+200 daPa to -400 daPa)at a pressure sweep rate of 50 daPa/sec. Condition 4involved measuring the TPP and admittance values in the reverse pressure sweep direction (-400 daPa to +200 daPa)at a pressure sweep rate of 50 daPa/sec,i.e. Reverse sweep direction at low rate (RSLR). Further,ipsilateral ARTs atoctave frequencies between 500 Hz and 4000 Hz was estimated at the measured TPP for each of the conditions. ART is considered as the lowest stimulus level (a step size of 2 dB HL was used) that produced a minimum stimulus-associated change of 0.03 mmho in the acoustic admittance. The measurements were carried out in a randomized order to avoid order effects and documented the TPP, admittance, ipsilateral ART between 500 and 4000 Hz for all the participants.

Statistical analysis

We analyzed the collected data for the effects of the pressure sweep direction and sweep rate on the TPP and ARTs, separately for each group (Group I and Group II) using SPSS version 21.Shapiro-Wilk test of normality revealed that some of the data obtained under each condition for both groups did not follow a uniform bell-shaped curve ($p<0.05$). Thus, the non-parametric Friedman test of differences among repeated measures was used to compute the statistical significance of the differences between the conditions. Further, when the data was significantly different between conditions, Wilcoxon's signed-ranks test was used to test the differences between the two conditions. The present study did not analyze between-group comparisons.

RESULTS

Tympanic peak pressure measurements

The TPP data obtained from our study was averaged, and the descriptive parameters are presented in Table 1.It was observed that in both groups, the reverse pressure sweep direction (RSHR and RSLR) yielded a lower TPP value than the forward direction (FSHR and FSLR).

Table 1: Mean (Standard deviation) values of the static admittance and tympanic peak pressure for both the subject groups across the conditions measured.

Conditions	Tympanic peak pressure (in daPa)		Static admittance (in mmho)	
	Group I (Normal Admittance)	**Group II** (Increased Admittance)	**Group I** (Normal Admittance)	**Group II** (Increased Admittance)
Condition 1 - FSHR	16.00 (13.07)	22.89 (12.40)	0.63 (0.28)	2.51 (0.72)
Condition 2 - RSHR	-10.58 (14.97)	-17.89 (13.16)	0.67 (0.24)	2.67 (0.86)
Condition 3 - FSLR	2.20 (8.91)	4.74 (10.07)	0.58 (0.24)	2.67 (0.72)
Condition 4 - RSLR	0.60 (7.12)	-6.05 (5.16)	0.59 (0.22)	2.61 (0.68)

With respect to the TPP data measured for the participants with normal admittance (group I), the Friedman test of differences revealed a statistically significant difference among the four conditions (χ^2=45.47; p<0.01). Further,we analyzed the data using the Wilcoxon'ssigned-ranks test to identify any differences among the individual pairs of conditions. The results indicated that the between-condition differences were significant (p<0.01) for all pairs of conditions, exceptbetweenthe FSLR and RSLR (Z=-1.04; p=0.16). As shown in table 1, these results indicatedthat the highest positive TPP was obtained with the conventional procedure i.e. FSHR, whereas the lowest TPPwas obtained with thereverse pressure sweep direction at a rate of 200daPa/sec (RSHR). However, no difference was found in theobtained TPP between the conditions of the pressure sweep directionat a sweep rate of 50daPa/sec (FSLR and RSLR). Also, reversing the direction of the pressure sweep resulted in a reduction of an average 26.58 daPa of TPP at a pressure sweep rate of 200daPa/sec and only a changeof 1.6daPa at a pressure sweep rate of 50daPa/sec for individuals with normal admittance.

Similarly,in the experimental group of individuals with high admittance (Group II), the Friedman test revealed a significant difference among the four conditions (χ^2=49.52; p<0.01). Additionally, the Wilcoxon'ssigned-ranks test revealed that the between-condition differences were significant (p<0.01) for all pairs of conditions. Similar to the results in ears with normal admittance, highest positive TPP was obtained with the conventional procedure (FSHR) and the lowest TPP was obtained with the reverse pressure sweep direction at a rate of 200 daPa/sec(RSHR). These results indicate that both the sweep pressure direction and the sweep pressure ratesignificantly affect the TPP in high admittance ears. Thus,for individuals with high admittance, reversing the pressure sweep direction resulted in a reduction in average TPP that measured 40.79 daPa at a pressure sweep rate of 200daPa/sec and only a change of 10.79daPa at a pressure sweep rate of 50daPa/sec.

Static admittance measures

We averaged the static admittance data obtained from the participants, and the descriptive parameters were provided in Table 1.Using the Friedman test of differences in individuals with normal admittance (group I), revealed a significant difference among the conditions (χ^2=13.58; p<0.01). Individual comparisons across conditions with the Wilcoxon'ssigned-ranks test revealed a significantly higheradmittance inRSHRcompared to that measuredinFSLR (Z=-2.40; p=0.016) and RSLR (Z=-2.46; p=0.014). These observations indicated that the admittance obtained with a reverse pressure sweep direction at a pressure sweep rate of200daPa/sec was significantly higher than that obtained at a pressure sweep rate of50daPa/sec. Furthermore, we did not find any significant difference in the static admittance measures among the four conditions for individuals in group II with high admittance(χ^2=5.62;p=0.131).These results indicate that neither the sweep pressure direction nor the sweep pressure rate have a significant effect on the admittance measure in individuals with high compliance.

Acoustic reflexes measures

Ipsilateral acoustic reflex thresholds measured in each of the four conditions in ears with normal admittance is depicted in Figure 1. Most of the data obtained from normal admittance ears (group I) was distributed within a 10-dB HL range and was approximately equal at all the tested frequencies. Using the Friedman test of differences, the ARTs monitored inthe four experimental conditions at each of the four octave frequencies (500 Hz to 4000 Hz) for the normal admittance ears (group I) indicated a significant difference only at 500 Hz (χ^2=9.06; p=0.03) and 1000 Hz (χ^2=7.95; p=0.05); However, no significant differenceswas observed among the conditions at

2000 Hz (χ^2=3.57; p=0.31) and 4000 Hz (χ^2=0.69; p=0.88).In addition, individual pairwise comparisons (between conditions) with the Wilcoxon'ssigned-ranks test revealed that at 500 Hz,the ART obtained in FSHR was significantly higher than that obtained in RSHR (Z=-2.02; p=0.04).However, at 1000 Hz, the ART obtained in FSLR was significantly higher than that obtained in RSHR (Z=-2.49; p=0.01), and also significantly higher than that obtainedin RSLR (Z=-2.12; p=0.03). Overall, these findings revealed that the ipsilateral ARTs are sensitive to the pressure monitored only at 500 Hz and 1000 Hz in ears with normal compliance.The results of the present study suggest that the lowest (better) ARTs are measured at a peak pressure obtained by sweeping pressure from -400 daPa to +200 daPaand at a rate of 200 daPa/sec.

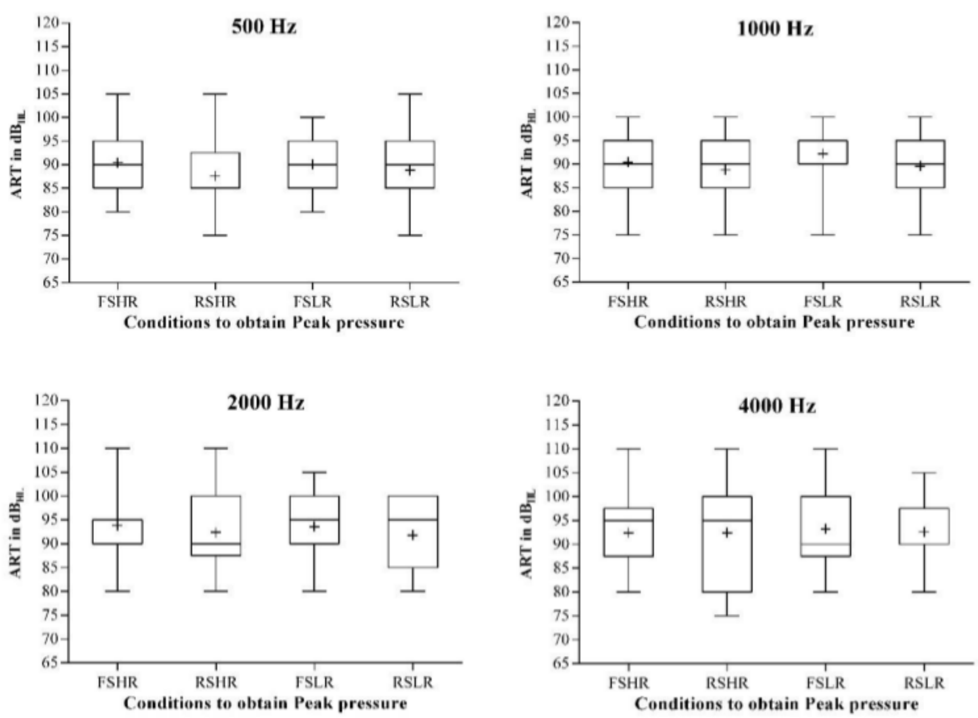

Figure 1: Acoustic Reflex Threshold for ears with normal/lower admittance. Data represented as box plots with Tukey whiskers ('+' represent mean value) across different conditions at different frequencies.

Whereas, the ART data obtained for ears with high compliance (group II)is depicted in Figure 2. The data obtained for this group was varied more than a range of 10 dB HL in each frequency, and had a large variation across frequencies. Using the Friedman test of differences, the differences in ARTs among conditionsfor individuals with high compliance earsindicated a significant difference among conditions at all the tested frequencies, i.e., at 500 Hz (χ^2=9.84; p=0.02), 1000 Hz (χ^2=14.83; p<0.01), 2000 Hz (χ^2=9.41; p=0.02), and 4000 Hz (χ^2=13; p<0.01). Further, individual pairwise comparisons (between conditions)using Wilcoxon'ssigned-ranks test revealed that at 500 Hz, the ART obtained in FSLR was significantly lower than that obtained in FSHR (z=-2.65; p<0.01). At 1000 Hz, the ART obtained in FSHR was significantly higher than that obtained in the other conditions ($p\leq$0.05), and no significant differences were found among the conditionsRSHR, FSLR, and RSLR. At 2000 Hz, theART obtained in FSHR was significantly higher than that obtained inRSHR (z=-3.11; p<0.01) and FSLR (z=-2.34; p=0.02). Additionally,the ART obtained at 2000 Hz in RSLRwas significantly higher than that obtained in FSLR (z=-2.23; p=0.03).Similarly, significant difference was noted at 4000 Hz:the ART obtained in FSHR was higher than that obtained inRSHR (z=-2.86; p<0.01) andFSLR (z=-2.68; p=0.01). Overall, these results suggest that theARTsmonitored at a pressure obtained with a conventional sweep direction at a rate of 200daPa/sec wereapproximately 6.75dBhigher than the ARTs obtained using TPPsmeasured with a reverse sweep direction for thosefrequencies greater than 500 Hz.Among all the conditions studied, the lowest ARTs were monitored at a pressure obtained with a reverse pressure sweep direction and at a rate of 200daPa/sec.

However, the inter-subject variation in the ART data was lower when a lower pressure rate (FSLR and RSLR) was used to obtain the TPP measurement, as shown in figure 2. Of the lower pressure rate conditions, FSLR resulted in lower ARTs at all the frequencies (approximately lowered/ better by 4.22 dB at 500 Hz, 4.74 dB at 1000 Hz, 3.95 dB at 2000 Hz, and 3.68 dB at 4000 Hz) compared to FSHR (Conventional method).

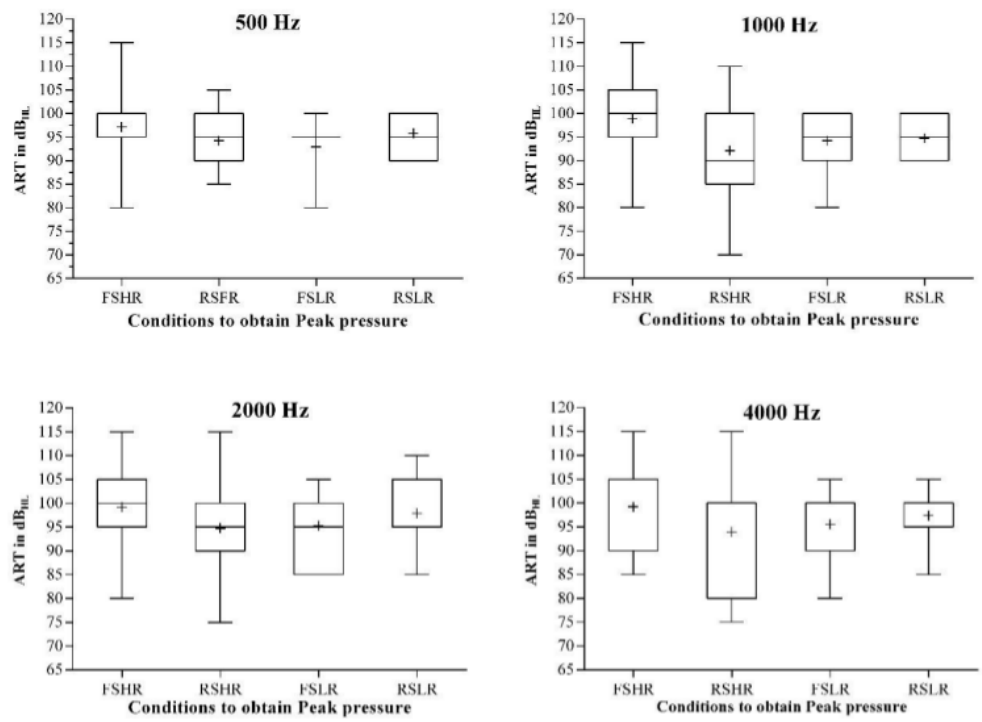

Figure 2: Acoustic Reflex Threshold for ears with high admittance. Data represented as box plots with Tukey whiskers (‘+’ represent mean value) across different conditions at different frequencies.

DISCUSSION

The present study evaluated the effects of sweep pressure direction and sweep pressure rate using two pressure rates and two pressure directionswith two different groups. Overall, the effects of these parameters on the TPP were different for both groups (Normal/Low admittance and High admittance). When the pressure swept from positive to negative for the tympanometry, more positive TPPs were obtained, than when the pressure swept in the reverse direction. Further, the TPP was closerto 0 daPa when the pressure rate was lower compared to when the sweeping pressure rate was higher. However, the difference in the measured TPP for two different pressure sweep directions was higher for individuals with higher admittance,andhigher with an increasedpressure rate. These findings across different conditions were similar tothe findings of earlier investigations (Shanks & Wilson, 1986). Studies on change in pressure direction also have indicated a significant effect with a change in the pressure rate on the TPP (Hergils, Magnuson, & Falk, 1990; Kobayashi et al., 1987; Shanks & Wilson, 1986; Therkildsen & Gaihede, 2005).The findings of the present study also are consistent even with high probe tone frequencies, especially at a higher pressure rate of 200 daPa/sec(Bian, 2014; Kim, 2003). Though TPP varies, the static admittance values obtained with different pressure directions and rates were not significantly different for the normal/low compliance and the high compliance groups. 10 These findings are in agreement with earlier studies thathave demonstrated 10 that the direction of pressure change and the pressure sweep rate has no effect on middle ear admittance(Bian, 2014; Kim, 2003). It is understood that the effect of TPP does not have a significant effect on admittance. 2 In a healthy individual, the maximum sound is transmitted through the middle ear when the ambient air pressure in the ear canal is equal to the pressure in the middle ear. TPP play a significant role in equalizing the 6 pressure between ear canal and middle ear thereby allowing maximum energy entering into middle ear(Robinson, Thompson, & Allen, 2016).

With respect to the ARTs monitored, it is evident that in individuals with high compliance middle ear systems, better ARTs were measured with a pressure obtained in a reverse sweep pressure direction and a pressure rate of 200 daPa/sec (Condition 2- RSHR), for all the experimental conditions. However,with respect to within group data comparisons, the ART data obtained in RSHR (Condition 2) showed high across-subject variations. These variations were lesser in the measured ARTs with reduced pressure sweep rate (Condition 3- FSLR). Overall, these results indicatethat in individuals with high admittance ears, slight pressure changes inthe external ear canal during the monitoringof acoustic reflexes across different frequencies havesignificant effects on the ARTs.In addition, the results of the present study show that at a rate of 50daPa/sec, the measured TPPs with a change in the pressure sweep direction do not significantly alter the ARTs.

Findings of the study indicate a distinctive effect of the ARTsof the measured TPP in all the four conditions of the pressure sweep direction and rate, mainly with respect to individuals with high compliance ears. These findings are in agreement with earlier studies wherein a shift of negative pressure greater than –50 daPa relative to the TPP produces significant increases in the ipsilateral ARTs in subjects with increased ear compliance(DiGiovanni & Ries, 2007; Martin & Coombes, 1974; Rizzo & Greenberg, 1979).A significant increase in ARTshas been reported for pressures at and beyond ±80 daPa(Rizzo & Greenberg, 1979).

In clinical practice, tympanometry is commonly used to detect the middle ear status for identification of middle ear disorders. However, the sensitivity and specificity of using 226 Hz tympanometry is reported to be poor(Browning, Swan, & Gatehouse, 1985; Kaf, 2011; Shahnaz & Polka, 1997).Bhatta and Adhikari (2008) noted that type A_s and type A_d has poor sensitivity and specificity in identifying middle ear pathologies and thus requires additional test tools to confirm the diagnosis. As it is evident from thepresent study that the ARTs measured with a lower pressure rate showed lower variations across ears, indicating lower inter-individual variations and elicit ART at the lower intensity level. This reduces the bias of the clinician in confirming the presence of ARTs and hence, improves the sensitive of the test to some extent. It is therefore significant that the accuracy of a diagnostic tool be measured applicably, in order to correctly identify middle ear pathologies for the benefits of the patients(Bossuyt, Reitsma, Linnet, &Moons, 2012), hence the value of the current study. Future studies of ART on high admittance ears may be performed on large samples to check influence of pressure direction and rate with those having absent reflexes.

CONCLUSION:

To conclude, clinicians are encouraged to use a lower pressure sweep rate (50 daPa/sec) and a conventional pressure sweep direction (positive pressure to negative pressure)to measure peak pressure, mainly with respect to individuals with increased ear admittance. Such measured TPPs could be used to monitor acoustic reflexes with more stability, and better results could be obtained. This could improve the sensitive of the immittance measurements and confirmation of middle ear disorders to some extent. However, authors suggested to perform the study with large sample data to evaluate the improvement of the test sensitivity with the recommended procedure.

TABLES

Table 1: Mean (Standard deviation)values of the static admittance and tympanic peak pressurefor both the subject groups across the conditions measured.

Conditions	Tympanic peak pressure (in daPa)		Static admittance (in mmho)	
	Group I (Normal Admittance)	Group II (Increased Admittance)	Group I (Normal Admittance)	Group II (Increased Admittance)
Condition 1 - FSHR	16.00 (13.07)	22.89 (12.40)	0.63 (0.28)	2.51 (0.72)
Condition 2 - RSHR	-10.58 (14.97)	-17.89 (13.16)	0.67 (0.24)	2.67 (0.86)
Condition 3 - FSLR	2.20 (8.91)	4.74 (10.07)	0.58 (0.24)	2.67 (0.72)
Condition 4 - RSLR	0.60 (7.12)	-6.05 (5.16)	0.59 (0.22)	2.61 (0.68)

FIGURE LEGENDS

Figure 1: Acoustic Reflex Threshold for ears with normal/lower admittance. Data represented as box plots with Tukey whiskers ('+' represent mean value) across different conditions at different frequencies.

Figure 2: Acoustic Reflex Threshold (ART) for ears with high admittance. Data represented as box plots with Tukey whiskers ('+' represent mean value) across different conditions at different frequencies.

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